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<b>(21) International Application Number:</b> PCT/US92/04068 <b>(22) International Filing Date:</b> 14 May 1992 (14.05.92)  <b>(30) Priority data:</b> 699,769                      14 May 1991 (14.05.91)                      US  <b>(71) Applicants:</b> DANA FARBER CANCER INSTITUTE [US/US]; 44 Binney Street, Boston, MA 02115 (US). BIOPURE CORPORATION [US/US]; 68 Harrison Avenue, Boston, MA 02111 (US).  <b>(72) Inventors:</b> TEICHER, Beverly, A. ; 135 Hunting Road, Needham, MA 02192 (US). RAUSCH, Carl, W. ; 124 Sagamore Avenue, Medford, MA 02155 (US). HOPKINS, Robert, E., II ; 136 Cornet Stetson Road, Scituate, MA 02066 (US).	<b>(74) Agents:</b> BROOK, David, E. et al. ; Hamilton, Brook, Smith & Reynolds, Two Militia Drive, Lexington, MA 02173 (US).  <b>(81) Designated States:</b> AT, AT (European patent), AU, BB, BE (European patent), BG, BR, CA, CH, CH (European patent), CS, DE, DE (European patent), DK, DK (European patent), ES, ES (European patent), FI, FR (European patent), GB, GB (European patent), GR (European patent), HU, IT (European patent), JP, KP, KR, LK, LU, LU (European patent), MC (European patent), MG, MN, MW, NL, NL (European patent), NO, PL, RO, RU, SD, SE, SE (European patent).  <b>Published</b> <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>	
<b>(54) Title:</b> USE OF HEMOGLOBIN IN A METHOD FOR THE TREATMENT OF TUMORS WITH CHEMOTHERAPEUTIC AGENTS  <b>(57) Abstract</b>  A method is disclosed treating a tumor in a host by administering an ultrapurified polymerized hemoglobin solution to the host and also administering a chemotherapeutic agent to the host. In a particularly preferred embodiment, the hemoglobin is bovine hemoglobin.		

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## USE OF HAEMOGLOBIN IN A METHOD FOR THE TREATMENT OF TUMOURS WITH CHEMO-THERAPETIC AGENTS

DescriptionBackground of the Invention

5           Solid tumor masses in cancer patients have been found to be heterogeneous in oxygenation and to contain regions of hypoxia. See Vaupel. P., "Oxygenation of Human Tumors", Strahlenther. Onkol. 166:377-386 (1990); and Adams, G.E., The Clinical  
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15   Kallinowski, F. et al., "Tumor Tissue Oxygenation as Evaluation by Computerized-pO<sub>2</sub>-Histography", Int. J. Radiat. Oncol. Biol. Phys. 19:953-961 (1990); and  
20   Gatenby, R.A. et al., "Oxygen Distribution in Squamous Cell Carcinoma Metastases and Its Relationship to Outcome of Radiation Therapy", Int. J. Radiat. Oncol. Biol. Phys. 14:831-838 (1988).  
Preclinical studies, both in vitro and in vivo, have established that hypoxia protects tumor cells from the cytotoxic actions of radiation and chemotherapeutic agents and thereby may be a significant factor in  
25   therapeutic resistance. Adams, G.E. ibid;  
Sartorelli, A.C., "Therapeutic Attack of Hypoxic Cells of Solid Tumors: Presidential Address", Cancer Res. 48:775-778 (1988); Teicher, B.A. et al.,  
30   "Classification of Antineoplastic Agents by Their Selective Toxicities Toward Oxygenated and Hypoxic

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Tumor Cells", Cancer Res. 41:73-81 (1981); and  
Teicher, B.A. et al., "Classification of  
Antineoplastic Treatment by Their Differential  
Toxicity Toward Putative Oxygenated and Hypoxic Tumor  
5 Subpopulations in vivo in the FSaIIc Murine  
Fibrosarcoma", Cancer Res. 50:3339-3344 (1990).

Increased delivery of oxygen from the lungs can  
be a useful way of improving the oxygenation of solid  
tumor masses by altering the gradient of oxygen as it  
10 is absorbed from the vasculature and distributed into  
the tissue. Because of this, one strategy which has  
been attempted to overcome the problem of hypoxia in  
treating tumors involves the use of perfluorocarbon  
emulsions with oxygen or carbogen (95% oxygen/5%  
15 carbon dioxide) breathing. Holden, S.A. et al.,  
"Addition of a Hypoxic Cell Selective Cytotoxic Agent  
(mitomycin C or porfiromycin) to Treatment with  
Fluosol-D® /Carbogen/Radiation", Radiother. Oncol.  
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25 Hyperbaric Oxygen", Int. J. Radiat. Oncol. Biol.  
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Perfluorochemical Levels with Radiation Therapy"  
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solid tumor models, the use of perfluorocarbon  
emulsions with carbogen or oxygen breathing in  
5 conjunction with radiation therapy has produced  
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112:45-53 (1987); Mouler, J.E. et al., "Applicability  
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- 10 The effect of perfluorocarbon emulsions in carbogen or oxygen breathing with certain chemotherapeutic agents has also been studied in preclinical solid tumor models. Teicher, B.A. et al., "Classification of Antineoplastic Treatments by
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DA/Carbogen on Etoposide/Alkylating Agents Antitumor Activity", Cancer Chemother. Pharmacol. 21 281-285 (1988); Martin, D.F. et al., "Potentiation of Rat Brain Tumor Therapy by Fluosol and Carbogen", NCI Monogr. 6:119-122 (1988); and Kim, G.E. and C.W. Song, "The Influence of Fluosol-DA and Carbogen Breathing on the Antitumor Effects of Cyclophosphamide In Vivo", Cancer Chemother. Pharmacol. 25:99-102 (1989). With many chemotherapeutic agents, very positive therapeutic results have been obtained and several initial clinical trials have been carried out with Fluosol-DA and oxygen breathing with single anticancer drugs. See Gruber, M. et al., "Phase I/II Study of Fluosol<sup>®</sup>/O<sub>2</sub> in Combination with BCNU in Malignant Glioma", Proc. Amer. Assoc. Cancer Res. 31:190 (March 1990); Carewal, H. et al., "Fluosol/Oxygen in Combination with Cyclophosphamide in Advanced Non-Small Cell Lung Carcinoma (NSCLC): Phase I Results", Proc. Amer. Assoc. Cancer Res. 30:271 (March 1989); and Meyers, F. et al., "Phase I/II Study of Fluosol<sup>®</sup>/Oxygen in Combination with Weekly 5-Fluorouracil (5FU) in Metastatic Colorectal Carcinoma", Proc. Amer. Assoc. Cancer Res. 30:256 (March 1989).

Despite the initial success with the use of perfluorocarbon emulsions and carbogen or oxygen breathing in conjunction with ionizing radiation, these techniques have not proven entirely

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satisfactory. For example, perfluorocarbons have very limited oxygen-transport capability at ambient oxygen pressures. Blood delivers approximately 6% (v/v) oxygen to tissues at ambient pressures, whereas, at these same pressures, perfluorocarbon emulsions can only delivery about 2% (v/v).

#### Summary of the Invention

This invention relates to a method for treating a tumor in a host, including a human being, with ionizing radiation. In this method, an ultrapurified polymerized hemoglobin solution (UPHS) is administered to the host in an amount which significantly increases the antitumor effect of the radiation. In addition, the use of the hemoglobin solution, in contrast to the use of perfluorocarbon emulsions, has certain advantages. Hemoglobin is able to chelate and deliver oxygen under air-breathing conditions. Polymerized hemoglobins have a longer circulating half-life than many of the perfluorocarbon emulsions and, therefore, have a longer functional period post-administration. The acidic environments in tumors increase the off-loading of oxygen and, therefore, the oxygen delivery from hemoglobin, as should temperature elevation (i.e., clinical hyperthermia). Hemoglobin solutions also have less retention in normal tissues, which is a concern with many perfluorocarbon preparations.

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Brief Description of the Figure

Figure 1 is a plot of the surviving fraction of FSAIIC tumor cells and bone marrow granulocyte-macrophage colony forming units (CFU-GM) versus dose of Melphalan (MEL) administered to mice alone or with a single dose of ultrapurified polymerized bovine hemoglobin solution (UPBHS) administered immediately prior to MEL injection.

Figure 2 is a plot of the surviving fraction of FSAIIC tumor cells and bone marrow CFU-GM versus dose of Cyclophosphamide (CTX) administered to mice alone or with a single dose of UPBHS immediately prior to CTX injection.

Figure 3 is a graph of  $pO_2$  measurements made of 13672TB mammary carcinoma, using a histogram.

Figure 4 graphically illustrates that the ultrapurified polymerized bovine hemoglobin solution called Hemopure alters the oxygenation profile of the tumor.

Figure 5 is the  $pO_2$  measurements made of 9L brain tumor using a histogram.

Figure 6 graphically illustrates that the ultrapurified polymerized bovine hemoglobin solution called Hemopure improves the oxygenation of the 9L tumor whether the animals were breathing air or carbogen.

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Detailed Description of the Invention

This invention relates to a method for treating a tumor in a host. The host can be any species which develops solid tumors or masses of tumor cells  
5 containing oxygen heterogeneity. Examples of hosts include but are not limited to, reptiles, amphibians, avians and mammals, including human beings, as well as domestic animals such as dogs, cats, cows and horses.

10 Tumors treatable by this method include those in which oxygen heterogeneity, including regions of hypoxia, protect tumor cells against the cytotoxic action of chemotherapeutic agents. These are usually solid tumors, such as sarcomas, carcinomas,  
15 lymphomas, etc. However, in certain cases of dispersed tumor cells form which can produce regions of oxygen heterogeneity, as well.

As used herein, the terms "chemotherapeutic agent" is employed to include chemical and biological  
20 agents, including small molecules and larger molecules, such as peptides, proteins, lymphokines, antibodies, tumor necrosis factor, conjugates of antibodies with toxins, and other chemical or biological molecules which have an antitumor effect  
25 which is oxygen dependent.

There are a variety of known classes of small molecule antitumor chemotherapeutic agents. These include alkylating agents, such as Melphalan (MEL), Cyclophosphamide (CTX), cis-Diamminedichloroplatinum

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(II) (CDDP) and N N'-bis(II-chloroethyl)-N-nitrosourea (BCNU). Another general class of antitumor chemotherapeutic agents are the antimetabolite, such as 6-Mercaptopurine, 5-fluorouracil, fluorodeoxyuridine, cytosine arabinoside, methotrexate and thioquinone. Antibiotics are another general class of antitumor chemotherapeutic agents including drugs such as actinomycin, daunorubicin, adriamycin and bleomycin. Still yet another class is the vinca alkaloids, including etoposide, vincristine and vinblastine.

Mixtures of more than one antitumor chemotherapeutic agent can, of course, be administered. Indeed, it is often preferred to use mixtures of antitumor agents to treat tumors, especially agents from the different classes of agents. For example, mixtures of methotrexate and a cis-platinum compound are often used to treat various tumors.

The chemotherapeutic agent can be administered to the host parenterally, for example, by subcutaneous, intravenous or intramuscular injection or by absorption through a bodily tissue, such as the digestive tract, the respiratory system or the skin. The form in which the antitumor agent is administered (e.g., capsule, tablet, solution, emulsion) will depend, at least in part, on the route by which it is administered.

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The chemotherapeutic agent is administered in a therapeutically effective amount. This amount will be determined on an individual basis and will be based, at least in part, in consideration of the host's size, the specific tumor to be treated, the severity of the symptoms to be treated, the results sought, and other such considerations. An effective amount can be determined by one of ordinary skill in the art employing such factors and using no more than routine experimentation.

In order to increase oxygen transport of the site of a tumor, an ultrapurified polymerized hemoglobin solution (UPBHS) is administered to the host. Although not essential, it is preferred to administer the UPHS prior to administration of the antitumor agent. Also, the hemoglobin solution is preferably administered intravenously so that it is taken into the bloodstream of the host immediately.

As mentioned above, it is preferably to administer UPHS prior to administration of the chemotherapeutic agent. The amount of time between the administration of the hemoglobin and chemotherapeutic agent will depend upon factors such as the amount of time it takes the hemoglobin solution to be fully incorporated into the circulatory system of the host, the lifetime of the hemoglobin solution, etc. Since polymerized bovine hemoglobin has been found to remain in the host's

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blood stream for up to at least 48 hours, anytime during this period is sufficient.

Hemoglobin sufficient for the hemoglobin solutions can be derived from a wide variety of sources. These sources include human blood, such as outdated blood bank supplies. Additionally, the hemoglobin can be derived from a variety of mammalian sources such as horses, pigs, cows, sheep, etc.

In a preferred embodiment, the hemoglobin will be derived from a species in which the hemoglobin is chloride ion-dependent for oxygen transport rather than dependent upon 2,3-diphosphoglycerate (2,3-DPG) or other phosphate molecules. This is because 2,3-DPG, present in human red blood cells, is not available freely in the circulatory system of the host to effect oxygen uptake and release for hemoglobin solutions administered according to this invention. Thus, it is preferred to employ a hemoglobin which is chloride ion-dependent for oxygen transport, such as those hemoglobins derived from sheep, goats, cows and cats. See Bunn. J.F., "Differences in the Interaction of 2,3-Diphosphoglycerate with Certain Mammalian Hemoglobins", Science 172:1049-50 (1971); Breepel, P.M. et al., "Interaction of Organic Phosphates with Bovine Hemoglobin -- I Oxylabile and Phosphate Labile Proton Binding", Pflugers Arch. 389:219-25 (1981); and Fronticelli, C. et al., "Solvent Regulation of Oxygen Affinity and Hemoglobin -- Sensitivity of

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Bovine Hemo-Globin to Chloride Ions", J. Bio. Chem.  
259:10841-4 (1984). Bovine hemoglobin is  
particularly preferred because of its proven ability  
to transport oxygen in human beings and other  
5 mammals, in a chloride ion-dependent way, and because  
of its low antigenicity in human beings when it has  
been ultrapurified.

In order to increase the useful life of  
hemoglobin in the circulation, it is polymerized or  
10 crosslinked by a variety of techniques. Crosslinking  
agents include dialdehydes, such as glyoxal, malonic  
dialdehyde, succinic dialdehyde, glutaraleehyde,  
adipaldehyde, 3-methylglutaraldehyde,  
propyladipaldehyde, phthalic dialdehyde,  
15 terephthaldehyde and malonic dialdehyde have been  
employed. See, in this regard, Bonsen et al., U.S.  
Patent Nos. 4,001,200; 4,001,401; and 4,053,590;  
Bonhard et al., U.S. 4,136,093 and U.S. Patent Nos.  
4,336,248; the teachings of each of which are  
20 incorporated herein by reference.

The polymerized hemoglobin solution is  
ultrapurified by various filtration and  
chromatographic procedures which have been described  
heretofore in the art. An ultrapure hemoglobin  
25 solution, according to this invention, is a  
hemoglobin solution which is substantially free of  
stroma, endotoxin, other pyrogenic substances,  
phospholipids, immunoglobulins and cellular-contained  
enzymes.



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A particularly preferred ultrapure polymerized hemoglobin solution is based upon bovine hemoglobin solution is based upon bovine hemoglobin. Such a bovine blood substitute has an endotoxin  
5 concentration of less than 0.5 endotoxin units/ml as measured by the LAL test; a phospholipid concentration of less than about 1 nanogram/milliliter and has a molecular weight distribution greater than 90% in the range of 68,000-  
10 500,000 daltons. This bovine hemoglobin solution also has an osmolarity measured by freezing point depression in the range of 180-320 milliosmols per liter; a hemoglobin content of 5-25 grams per deciliter; a met hemoglobin content of less than 20%;  
15 a  $p_{50}$  in the range of 18-36 mmHg; an intravascular half life of at least two days; a crosslinking profile on gel permeation chromatography of 50-70%.

Such ultrapurified polymerized bovine hemoglobin solution is made and sold by Biopure Corporation,  
20 Boston, MA under the trademark Hemopure. This and other ultrapurified hemoglobin solutions are described in International Patent Application PCT/US87/02967, published under WO88/03408, the teachings of which are hereby incorporated by  
25 reference.

Appropriate dosages of UPBHS can be determined by those skilled in the art using routine experimentation. The dose employed in the murine studies in the Examples herein was 12 ml/kg, which is

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13%-15% of the estimated circulatory volume, or 1.32 g protein/kg. This dose corresponds to 840 ml as the comparative human dose or 17%-19% of estimated circulatory volume, and 2.4 g protein in a 70 kg person. Multiple doses of UPHS, for example one before each chemotherapy treatment, are, of course, useful with this invention and can be preferred in many cases.

The techniques for treating tumors described herein can be employed at normal body temperatures or at elevated body temperatures (hyperthermia).

Although not required, it is preferred to have the host breathe oxygen-enriched gas prior to and post administration of the ionizing radiation. This can be done by having the host breath oxygen-enriched air, 100% oxygen or carbogen (95% oxygen/5% CO<sub>2</sub>), or in certain cases exposing the host to hyperbaric oxygen conditions.

This invention will now be further and more specifically described by the following examples.

#### Example I

##### Tumor Growth Delay with UPHBS

The FSaII fibrosarcoma (FSaIIC), adapted for growth in culture, was employed. See Rice, L. et al., "The Radiosensitivity of a Murine Fibrosarcoma as Measured by Three Cell Survival Assays", Br. J. Cancer 41:240-245 (1980). 2x10<sup>6</sup> FSaIIC cells,

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prepared from a brei of several stock tumors, were implanted intramuscularly into the legs of 8- to 10-week old male C3H/FeJ mice (The Jackson Laboratory, Bar Harbor, ME). When the tumors were approximately 100mm<sup>3</sup> in volume, 0.3 ml (12 ml/kg; 1.32 gm protein/kg) of ultrapurified polymerized bovine hemoglobin solution (UPBHS) was injected via the tail vein. The UPBHS solution was obtained from Biopure Corporation, Boston, MA and was a polymerized form of a highly purified bovine hemoglobin solution. It contained 11±2 gm/deciliter of bovine hemoglobin. P<sub>50</sub> measurements of UPBHS in three assay systems and under conditions designed for testing human hemoglobin gave values of 17 mmHg to 23 mmHg. The hemoglobin content had a molecular weight of range from 68,000 to 500,000 (w/v). It contained sodium (145 mM/L), chloride (140mM/L) and potassium (4.0 mM/L) in a buffer solution (pH 7.8 ± 0.4). The circulating half life of this UPBHS was about 2.5 days. DeVenuto, F., "Evaluation of Human and Bovine Modified-Hemoglobin Solution as Oxygen-Carrying Fluid for Blood Volume Replacement", Biomat. Art. Cells, Art. Org. 16:77-82 (1988); and Winslow, R.M., "Optimal Hematologic Variables for Oxygen Transport Including P<sub>50</sub>, Hemoglobin Cooperativity, Hematocrit, Acid-Base Status, and Cardiac Function", Biomat., Art. Cells and Art. Organs 16:149-172 (1988).

Immediately after the administration of UPBHS, 10 mg/kg Melphalan (MEL), 150 mg/kg Cyclophosphamide

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(CTX), 10 mg/kg cis-diaminodichloroplatinum(II) (CDDP) or 15 mg/kg N,N-bis(2-chloroethyl)-N-nitrosourea (BCNU) was administered by intraperitoneal unjection of 0.2 ml of phosphate buffered normal saline containing the drug. CTX and MEL were purchased as pure powders from Sigma Chemical Company, St. Louis, Missouri. CDDP was obtained as a gift from Bristol Meyers-Squibb Company, Wallingford, CT. BCNU (Carmustine) was purchased from the Dana-Farber Cancer Institute Pharmacy.

The mice were allowed to breath air or were placed in a circulating atmosphere of 95% O<sub>2</sub>/5% CO<sub>2</sub> (carbogen) for six hours and then removed to air. The progress of each tumor was measured three times weekly until it reached a volume of 500mm<sup>3</sup>. Tumor growth delay was calculated as the days taken by each individual tumor to reach 500 mm<sup>3</sup> compared to the untreated controls. Each treatment group had seven animals and the experiment was repeated three times. Days of tumor growth delay are the mean  $\pm$  SE for the treatment group compared to the control.

Data on the delay of tumor growth were analyzed with a BASIC program for the Apple II minicomputer. The program derives the best fit curve for each set of data, then calculated the median, mean and standard error of the mean for individual tumor volumes and the day on which each tumor reached 500 mm<sup>3</sup>. Statistical comparisons were made with Dunn Multiple Comparisons Test.

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The results of these tumor growth delay experiments are presented below in Table 1.

## TUMOR GROWTH DELAYS, DAYS

5	Treatment	AA	PBHS/	Carbogen	PBHS/
	Group	Alone	AIR		Carbogen
	MEL (10mg/kg)	3.1±0.5	6.9±1.0	4.0±0.6	11.1±1.3
	CTX (150mg/kg)	3.6±0.4	7.4±0.7	5.0±0.5	16.5±1.8
10	CDDP (10mg/kg)	7.4±0.8	9.6±1.1	7.6±0.3	14.1±1.6
	BCNU (15mm/kg)	2.5±0.3	3.8±0.5	3.3±0.3	5.7±0.9

Neither PBS nor the PBS/carbogen alone had any effect on the growth of the FSaIIC fibrosarcoma. The addition of UPBHS to treatment with MEL resulted in a 2.2-fold increase in the tumor growth delay produced by MEL from about 3 days to about 7 days. Although carbogen breathing (6 hours) resulted in a small increase in tumor growth delay compared with MEL and air breathing, the combination of PBHS and carbogen produced a 3.6-fold increase in the tumor growth delay compared with MEL alone. The addition of UPBHS to treatment with a single dose of CTX resulted in a

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2.1-fold increase in the tumor growth delay produced by CTX alone. Breathing a carbogen atmosphere for 6 hours post drug administration resulted in a small increase in the tumor growth delay produced by CTX; however, the combination of UPBHS and carbogen breathing was much more effective resulting in a 4.6-fold increase in tumor growth delay to about 16.5 days from 3.6 days for the drug alone.

The tumor growth delay produced by CDDP was less affected by the addition of PBHS to treatment with the drug than was either MEL or CTX. There was only a 1.3-fold increase in tumor growth delay with PBHS and CDDP compared with CDDP alone. Carbogen breathing for 6 hours following drug administration had no significant effect on the tumor growth delay produced by CDDP. The combination of PBHS and carbogen breathing was a more effective addition to treatment with C DDP and resulted in a 1.9-fold increase in tumor growth delay from 7.4 to 14.1 days.

The addition of PBHS to treatment with BCNU increased the tumor growth delay produced by BCNU by 1.5-fold. Although carbogen breathing for 6 hours post drug administration increased the tumor growth delay produced by BCNU to a small degree, a much larger enhancement in tumor growth delay was observed with PBHS and carbogen breathing in combination with BCNU. The combination of PBHS/BCNU and carbogen resulted in a tumor growth delay of about 5.7 days,

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which was a 2.3-fold increase over the 2.5 days obtained with BCNU alone.

#### Example II

##### Effects of UPBHS on Tumor Cell Toxicity and Bone Marrow Toxicity of MEL

5 The procedures and materials of Example I were employed, except as noted. In this Example, tumors were allowed to grow to approximately 100 mm<sup>3</sup> in volume, which took about one week after tumor cell  
10 implantation. At this time 0.3 ml of UPBHS was injected via the tail vein. Immediately afterward, MEL was administered by intraperitoneal injection. The animals were then allowed to breathe air or were placed in a circulating atmosphere of carbogen for 6  
15 hours and then removed to air. The mice were sacrificed 24 hours after treatment to allow for full expression of drug cytotoxicity and repair of potentially lethal damage. The tumors were excised under sterile conditions and single cell suspensions  
20 were prepared for a colony forming assay. See Teicher, B.A. et al., "Approaches to Defining the Mechanism of Fluosol-DA 20%/Carbogen Enhancement of Melphalan Antitumor Activity", Cancer Res. - 47:513-518 (1987); Teicher, B.A. et al., "Differential  
25 Enhancement of Melphalan Cytotoxicity in Tumor and Normal Tissue by Flusol-DA and Oxygen Breathing", Int. J. Cancer 36: 585-589 (1985); Teicher, B.A. et

-22-

al., "Effects of Various Oxygenation Conditions on the Enhancement by Fluosol-DA of Melphalan Antitumor Activity", Cancer Res. 47:5036-5041 (1987); Teicher, B.A. and S.A. Holden, "A Survey of the Effect of Adding Fluosol-DA 20%/O<sub>2</sub> to Treatment with Various Chemotherapeutic Agents", Cancer Treat. Rep. 71:173-177 (1987); Teicger, B.A. et al., "Effect of Various Oxygenation Conditions and Fluosol-DA on Cancer Chemotherapeutic Agents", Biomat., Art. Cells and Art. Organs 16:533-546 (1988). One week later, the plates were stained with crystal violet and colonies of more than 50 cells were counted. The untreated tumor cell suspensions had a plating efficiency of 8-12%.

Bone marrow toxicity was determined as follows. Bone marrow was taken from the same animals used for the tumor excision assays and colony forming assays were carried out in the same manner. Colonies of at least 50 cells were scored on an acculite colony counter (Fisher, Springfield, NJ). The results from three experiments, in which each group was measured in triplicate, were averaged.

The result for the tumor excision assays and bone marrow toxicity tests with MEL are plotted in Figure 1 wherein the surviving fraction  $\pm$  SE of cells from the treated groups are compared to untreated controls.

MEL killed FSAIIC cells in a log-linear manner with increasing dose of MEL. With addition UPBHS to



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treatment with MEL at a dose of 10 mg/kg, there was about a 10-fold increase in tumor cell killing compared with MEL alone. At higher doses of MEL, the enhancement in tumor cell killing with the combination treatment disappeared indicating that whatever effect UPBHS had to effect tumor cell killing could also be accomplished by increased dosage of the alkylating agent. In the bone marrow CFU-GM, the addition of UPBHS to treatment with MEL produced a 3-fold increase in cell killing across the entire dosage range of MEL examined.

### Example III

#### Effects of UPBHS on Tumor Cell Toxicity and Bone Marrow Toxicity of CTX

The procedures and materials of Example II were employed except that CTX was administered instead of MEL. The results are shown in Figure 2.

CTX killed increasing numbers of FSAIIC cells with increasing doses of the drug. The addition of UPBHS to treatment with a dose of 100 mg/kg of CTX resulted in about a 20-fold increase in the killing of FSAIIC cells. Although the differential between tumor cell kill by CTX alone and CTX plus UPBHS decreased as the dose of CTX was increased, at the highest dose (500 mg/kg) of CTX examined, there was about 9-fold greater kill of FSAIIC tumor cells with the combined treatment. The addition of the UPBHS to

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treatment with CTX resulted in a relatively small (2-3-fold) increase in the toxicity of the drug to bone marrow CFU/gm.

#### Example IV

5           Comparison Between Effects of UPHS and  
            Perfluorocarbon Emulsion Employed in  
            Combination with MEL

10           The procedures and materials of Example I were  
            employed except that Fluosol-DA was substituted for  
            UPHS. Fluosol-DA was obtained from Alpha  
            Therapeutics Corporation and is an emulsion  
            consisting of 25% (w/v) of the following  
            perfluorocarbons: 7 parts perfluorodecalin; 3 parts  
            per perfluorotripropylamine; Pluronic F-68 (2.7%,  
15           w/v); yolk phospholipids (0.4% as emulsifiers; and  
            glycerol (0.8%, w/v) as a cryoprotective agent. The  
            annex solution (electrolyte/bicarbonate solution)  
            furnished the preparation with physiological  
            osmolarity.

20           The specific procedures employing Fluosol-DA  
            have been described previously. See Teicher, B.A. et  
            al., "Approaches to Defining the Mechanism of  
            Fluosol-DA 20%/Carbogen Enhancement of Melphalan  
            Antitumor Activity", Cancer Res. 47:513-518 (1987);  
25           Teicher, B.A. et al., "Differential Enhancement of  
            Melphalan Cytotoxicity in Tumor and Normal t+Tissue  
            by Fluosol-DA and Oxygen Breathing", Int. J. Cancer

-25-

36:585-589 (1985); and Teicher, B.A. et al., "Effects of Various Oxygenation Conditions on the Enhancement by Fluosol-DA of Melphalan Antitumor Activity", Cancer Res. 47:5036-5041 (1987).

- 5           When MEL (10 mg/kg) was administered to animals bearing the FSaIIC fibrosarcoma in combination with Fluosol-DA and air breathing a tumor growth delay of about 6.5 days was observed. If carbogen breathing for 1 hour post drug administration was added to
- 10   therapy with Fluosol-DA and MEL a tumor growth delay of about 9.5 days resulted. Extending the carbogen breathing period to 6 hours did not alter the tumor growth delay produced by the MEL and Fluosol-DA combination (Teicher, B.A. et al., "Effect of Various
- 15   Oxygenation Conditions and Fluosol-DA on Cancer Chemotherapeutic Agents", Biomat., Art. Cels and Art Organs 16:533-546 (1988)), however, preparation of the MEL in the Fluosol-DA as a vehicle resulted in a much enhanced tumor growth delay of about 29.5 days
- 20   with carbogen breathing. The addition of PBHS to treatment with MEL as not quire as effective as combining MEL with Fluosol-DA and carbogen breathing resulting in a tumor growth delay of about 6.9 days. The combination of PBHS and carbogen breathing with
- 25   MEL was more effective than the combination of Fluosol-DA and carbogen breathing with MEL producing a tumor growth delay of about 11.1 days compared with about 9.5 days.

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Six hours of carbogen breathing are necessary to obtain a significant enhancement in the growth delay of the FSaIIC fibrosarcoma produced by CTX. Teicher, B.A. et al., "The Effect of Fluosol-DA and  
5 Oxygenation Status on the Activity of Cyclophosphamide In Vivo" Cancer Chemother. Pharmacol. 21:286-291 (1988). In the case of this drug the growth delay of the FSaIIC tumor with the treatment combination of CTX (150 mg/kg) with  
10 Fluosol-DA and carbogen breathing for 6 hours was about 12 days compared with about 3.6 days with CTX along. The 12 days of tumor growth delay obtained with this perfluorochemical emulsion/carbogen modulation of CTX was greater than the 7.4 days of  
15 tumor growth delay obtained with PBHS and air breathing with CTX but not as large as the 16.5 days of tumor growth delay obtained with the PBHS and carbogen breathing modulation of CTX.

#### Example V

20 The Eppendorf pO<sub>2</sub> histogram was used in the following experiment, this instrument allowed us to measure oxygen tension in tissues efficiently and reliably. We found the rat to be the preferred  
25 animal for these studies because it is easier to maintain their body temperature and respiration rate under anesthetic and because larger solid tumor masses can be grown in them.

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For our initial studies with Hemopure we used the rat 13762TB mammary carcinoma and the rat 9L gliosarcoma, both implanted subcutaneously in the hind leg of Fisher 344 female rats (200-250 grams).

5 The  $pO_2$  measurements made in the 13672TB mammary carcinoma are depicted in Figure 1. Under normal air breathing conditions approximately 55% of the measured points ( $n=1640$ ) are at values of  $<5$  mm Hg and the average  $pO_2$  in the tumor is 9.3 mm Hg. Upon

10 administration of 8 ml/kg or 12 ml/kg iv of Hemopure, the average  $pO_2$  in the tumors increases to about 22 mm Hg ( $n=500$  and 180, respectively). Breathing carbogen (95%  $O_2$ , 5%  $CO_2$ ) is effective in increasing the oxygenation of this tumor; however, the

15 combination of Hemopure and carbogen breathing is most effective. When the dose of Hemopure was 8 ml/kg, the percentage of the tumor at a  $pO_2$   $<5$  mmHg was reduced to about 16% and the average  $pO_2$  was increased to about 37 mmHg. With the higher doses of

20 Hemopure of 12 ml/kg, the percentage of the tumor at  $pO_2$   $<5$  mm Hg was about 3% and the average tumor  $pO_2$  was about 50 mmHg. Figure 2 graphically demonstrates that Hemopure alters the oxygenation profile of the tumor primarily by increasing the oxygen tension in

25 the more hypoxic 50 percentile of the tumor.

Our results thus far in the rat 9L gliosarcoma are even more hopeful. In the 9L brain tumor model about 46% of the tumor has a  $pO_2$  of  $<5$  mmHg and the average  $pO_2$  is  $\sim 7.4$  mmHg under normal air breathing

30 conditions ( $n=1862$ ). (Figure 3). When Hemopure (12

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ml/kg) was administered to the animals iv and normal air breathing maintained only about 13% of the tumor had a  $pO_2$  of <5 mmHg and the average tumor  $pO_2$  was about 18 mmHg. Carbogen is also effective in increasing the  $pO_2$  of the 9L gliosarcoma. Under carbogen breathing conditions of 28% of the tumor had a  $pO_2$  of <5 mmHg and the average tumor  $pO_2$  was about 42 mmHg (n=1870). Administration of Hemopure (12 ml/kg) along with carbogen breathing further increased the oxygenation of the 9L tumor such that only about 1.5% of the tumor had a  $pO_2$  <5 mmHg and the average tumor  $pO_2$  was about 69 mmHg. Figure 4 graphically demonstrates that the administration of Hemopure improves the oxygenation of the more hypoxic 50 percentile of the 9L tumor whether the animals are breathing air or carbogen.

As shown on Table 2, the Hemopure preparation was more effective at enhancing the growth delay produced by the various chemotherapeutic agents. A dose of 12 ml/kg (0.3 ml/dose) appeared to be about optimal for use with the anticancer drugs.

TABLE 2. Growth delay of the FSALIC fibrosarcoma produced by various chemotherapeutic agents alone or in combination with Hemopure I or Hemopure II.

Treatment Group	TUMOR GROWTH DELAY, DAYS				
	Treatment Alone	+Hemo I (0.3 ml)	+Hemo II (0.3 ml)	+Hemo II (0.5 ml)	+Hemo I (1.0 ml)
Cyclophosphamide (3 x 150 mg/kg)	7.8	9.7	22.9	26.2	12.3
melphalan (10 mg/kg)	3.1	6.9	11.5	10.7	8.8
cisplatin (10 mg/kg)	4.4	5.9	6.9	7.1	5.7
carboplatin (3 x 50 mg/kg)	4.3	7.4	9.4	8.6	7.4
etoposide (3 x 15 mg/kg)	2.8	3.8	9.5	8.8	3.42
5-fluorouracil (5 x 40 mg/lg)	7.6			10.9	

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CLAIMS

1. A method for treating a tumor in a host  
with a chemotherapeutic agent, comprising:
  - a) administering to said host an  
5                   ultrapurified polymerized hemoglobin  
                  solution in an amount sufficient to  
                  significantly increase the antitumor  
                  effect of said agent; and,
  - b) administering to said host an effective  
10                   amount of said chemotherapeutic agent.
2. A method of Claim 1 wherein said  
chemotherapeutic agent comprises an antitumor  
alkylating agent.
3. A method of Claim 1 wherein said hemoglobin  
15                   comprises a hemoglobin which is dependent upon  
                  chloride ion concentration for oxygen transport.
4. A method of Claim 1 wherein said hemoglobin is  
bovine hemoglobin.
5. A method of Claim 4 wherein said  
20                   chemotherapeutic agent comprises an antitumor  
                  alkylating agent.
6. A method of Claim 1 wherein said host is a  
mammal.



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7. A method of Claim 6 wherein said mammalian host is a human being.
8. In a method of treating a tumor in a mammalian host with an antitumor alkylating agent:
  - 5 The improvement of administering to said mammalian host, prior to treatment with said antitumor alkylating agent, an ultrapurified bovine hemoglobin solution in an amount sufficient to significantly
  - 10 increase the antitumor effect of said alkylating agent.
9. The improvement of Claim 8 wherein said mammalian host comprises a human being.

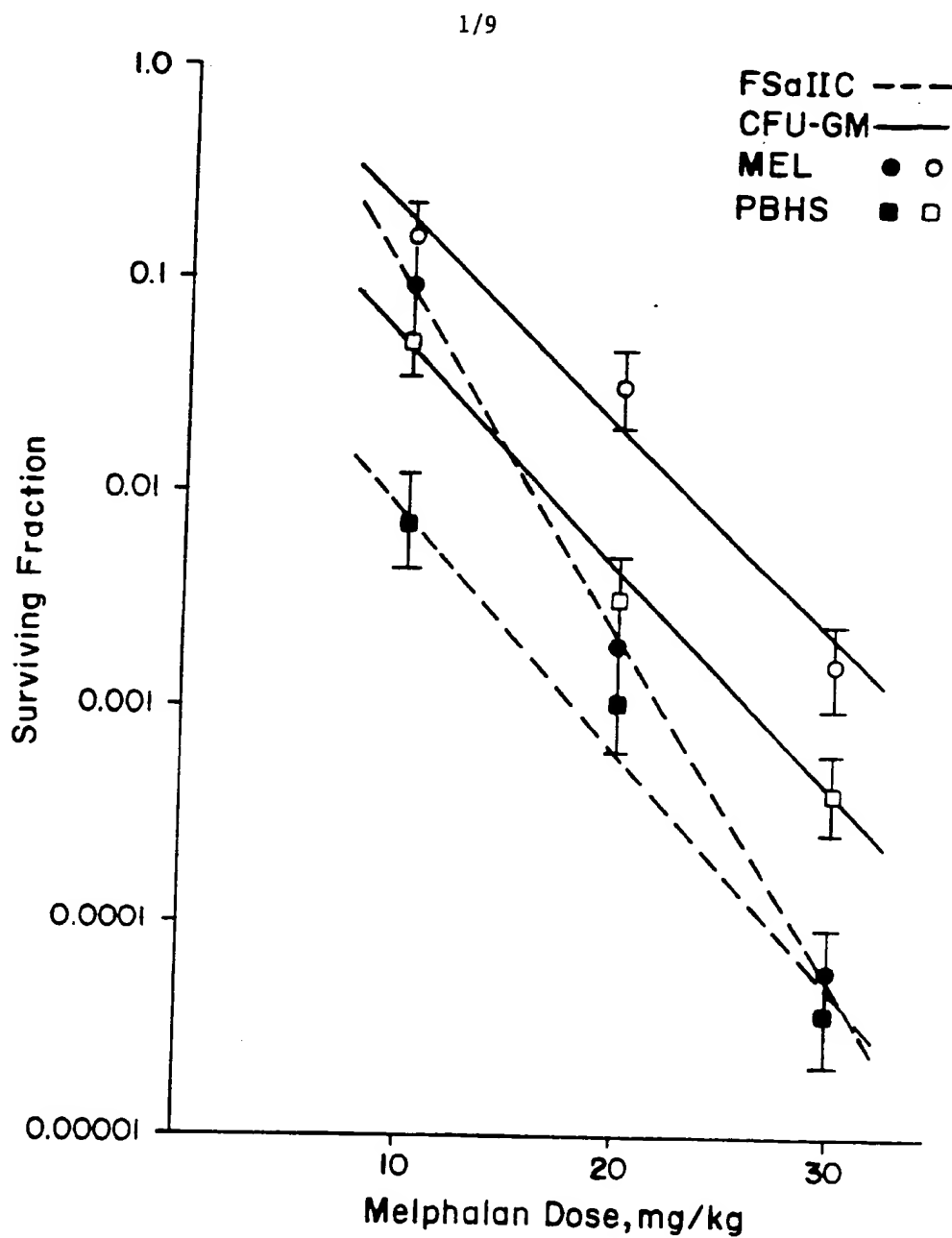


FIG. 1

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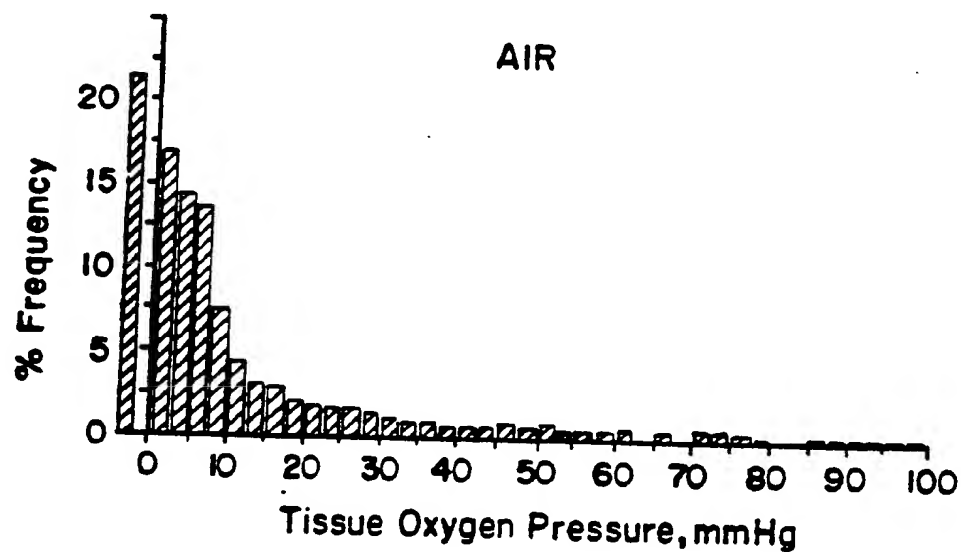


FIG. 3A

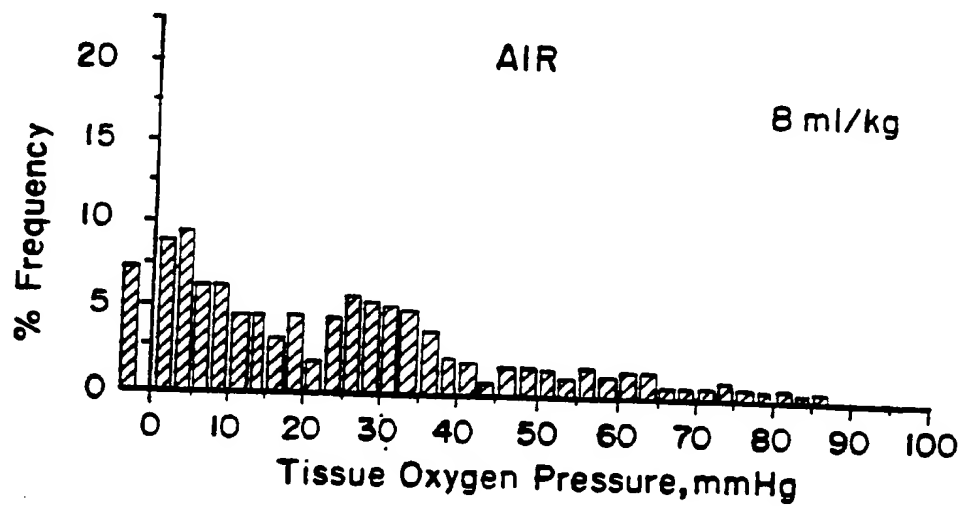


FIG. 3B

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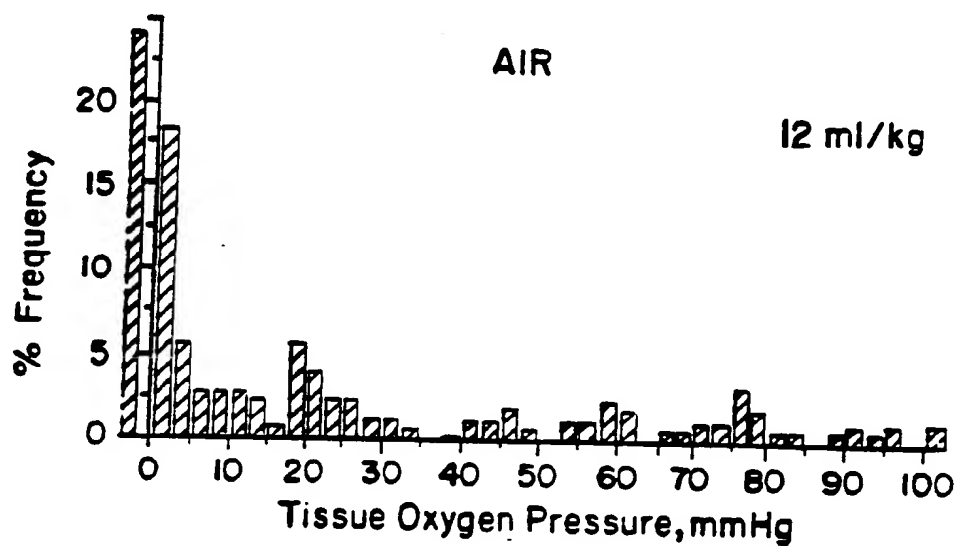


FIG. 3C

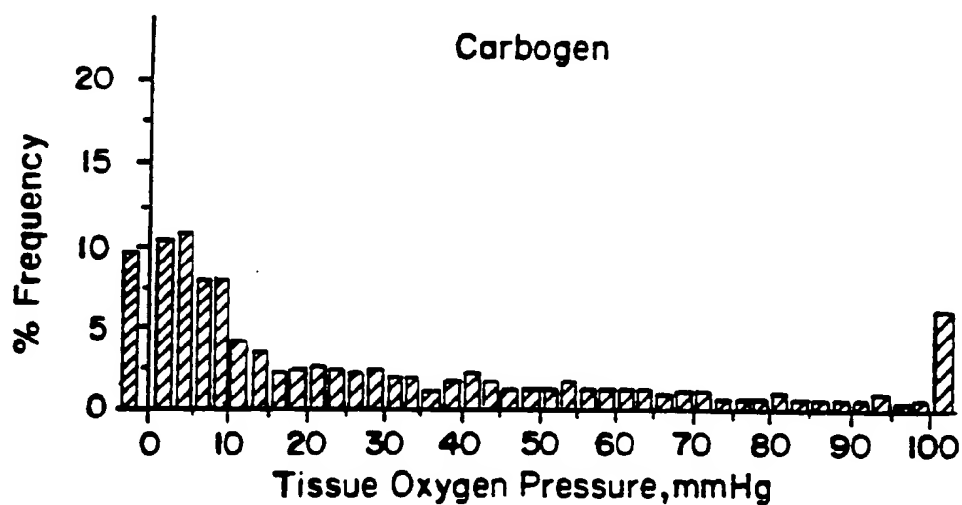


FIG. 3D

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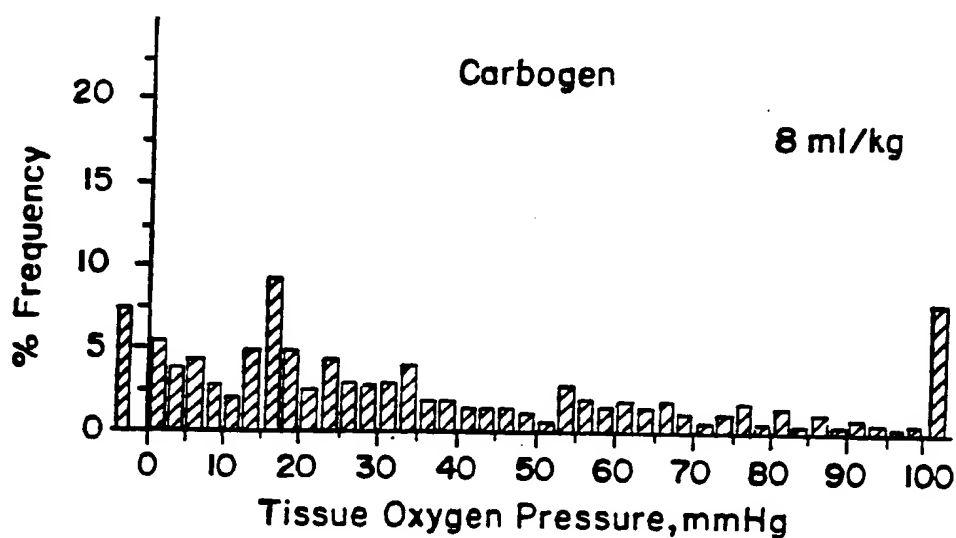


FIG. 3E

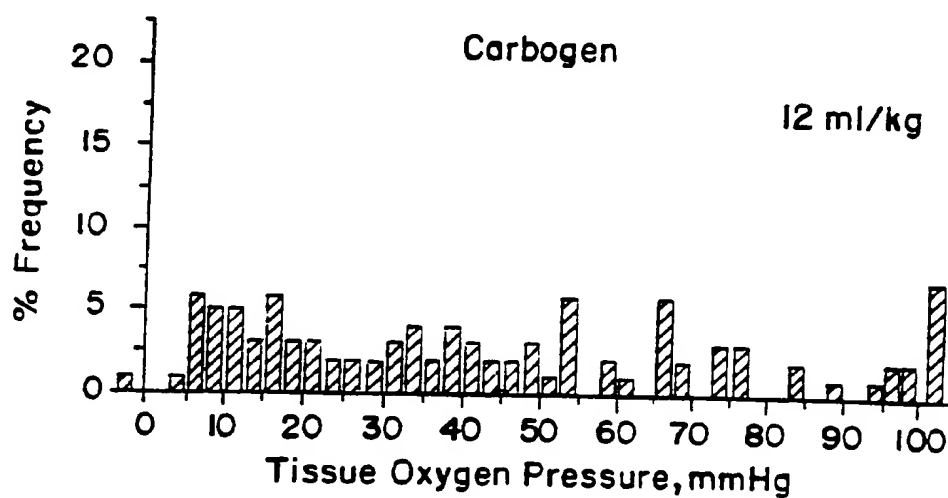


FIG. 3F

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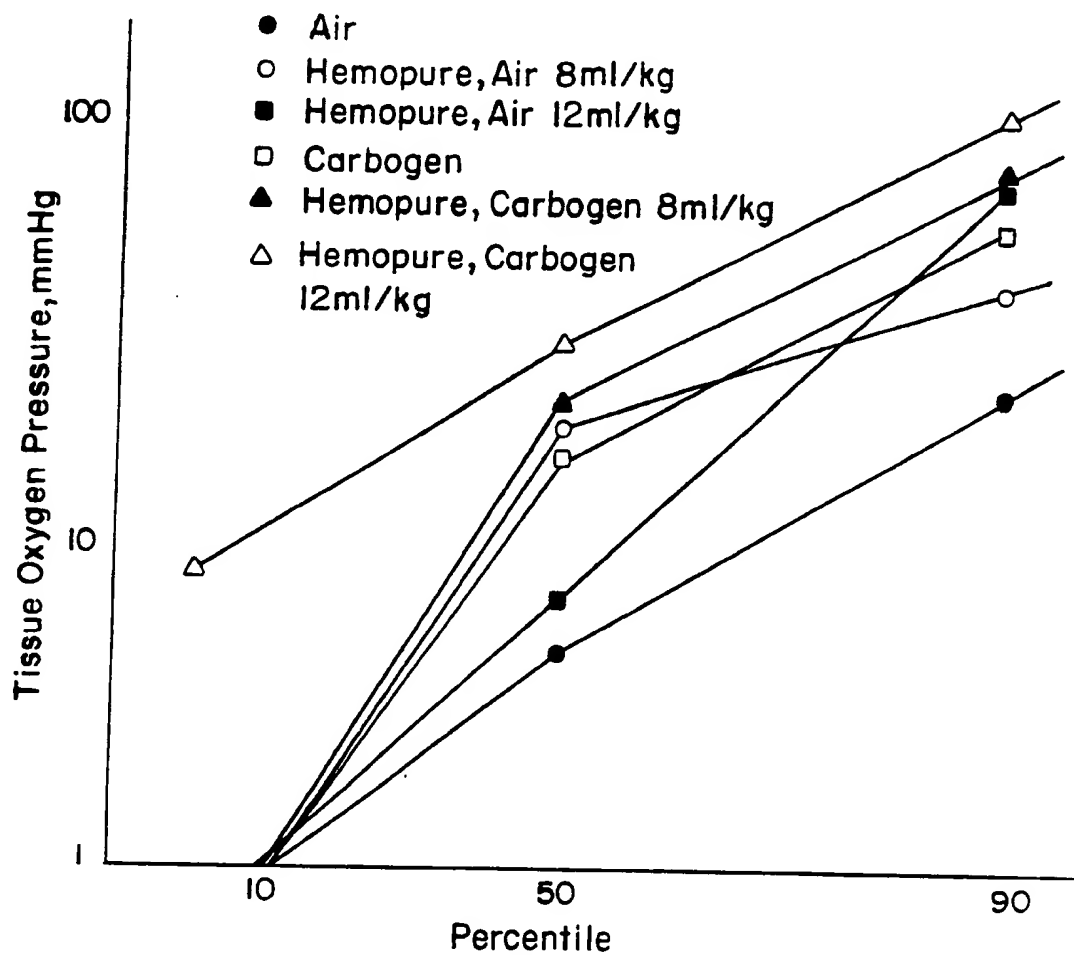


FIG. 4

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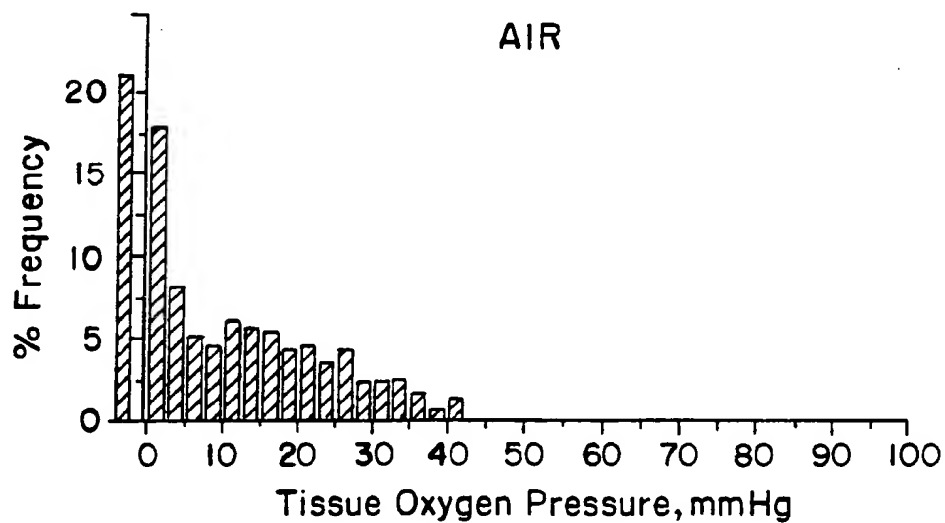


FIG. 5A

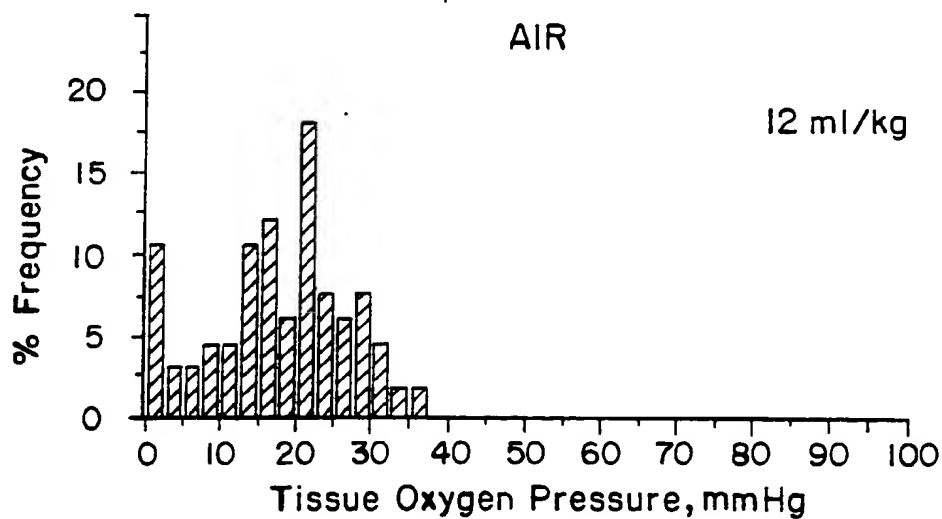


FIG. 5B

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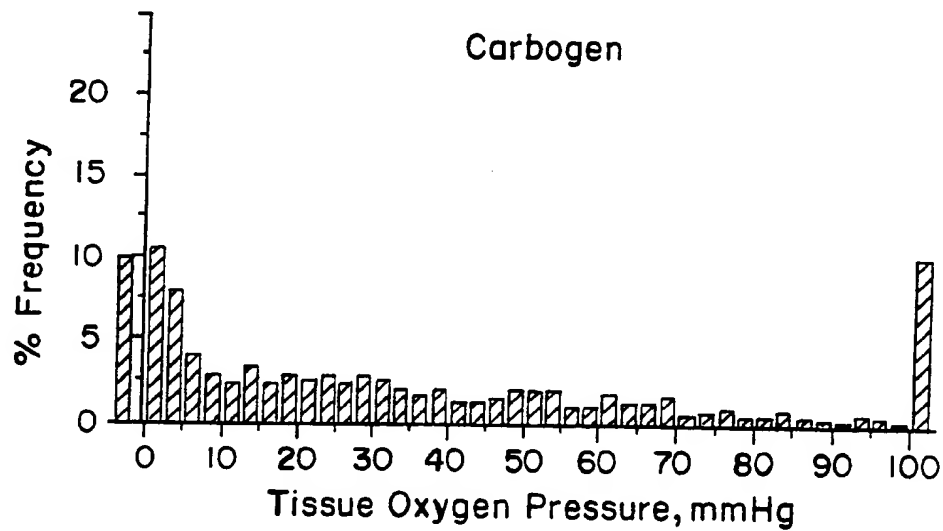


FIG. 5C

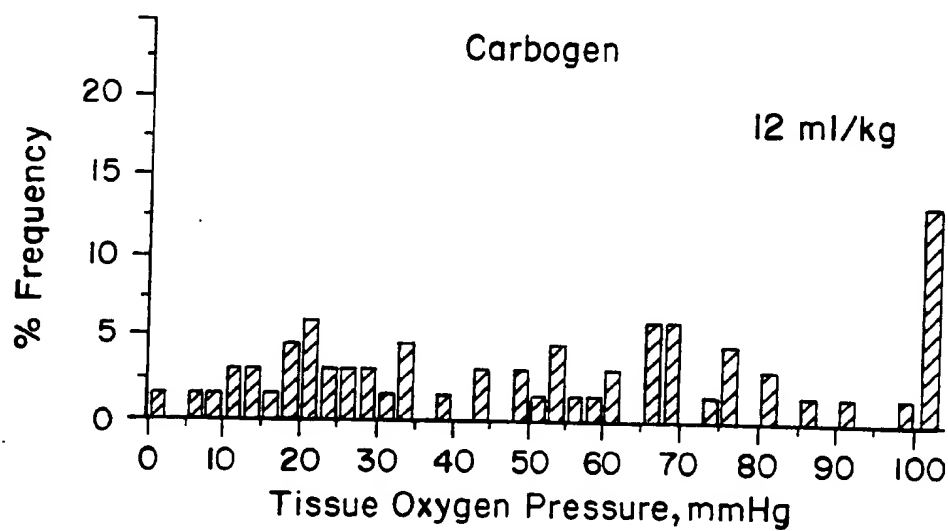


FIG. 5D



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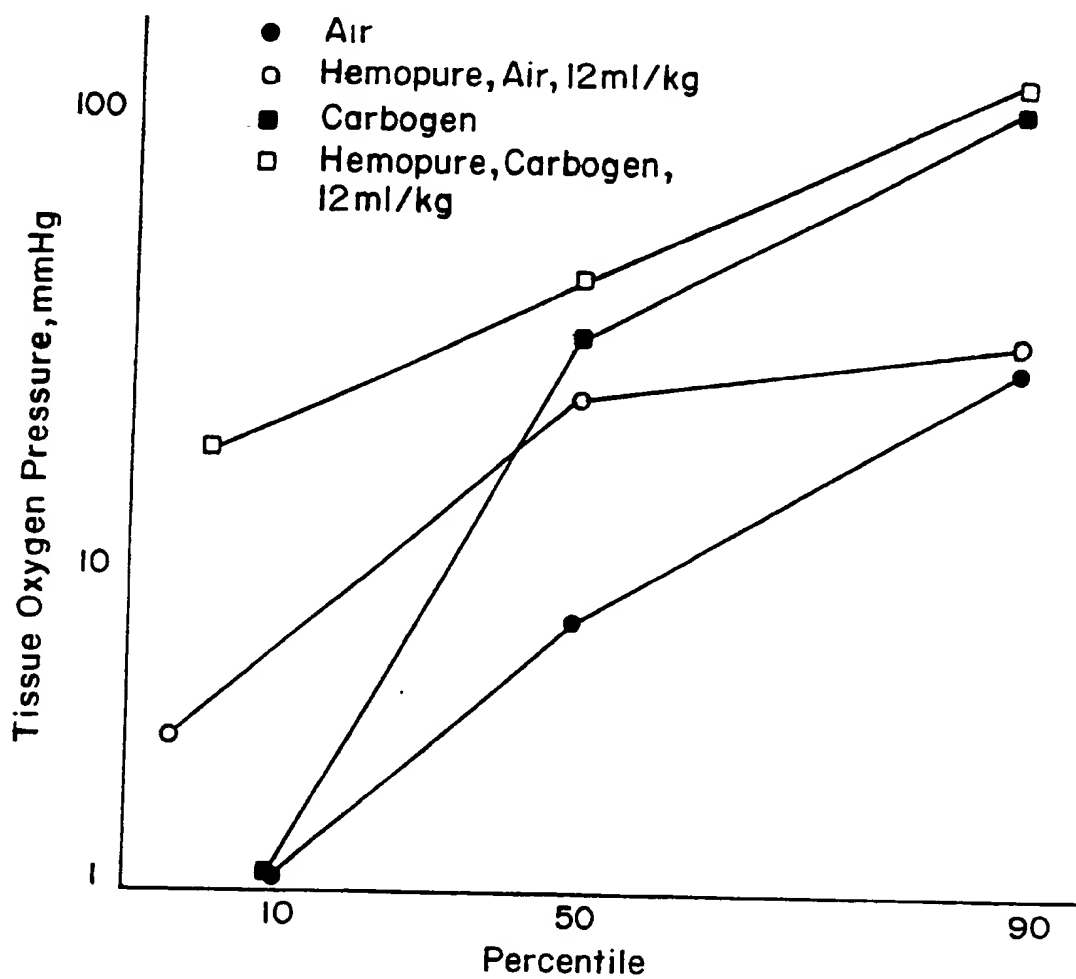


FIG. 6

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 92/04068

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> (If several classification symbols apply, indicate all) <sup>6</sup>		
According to International Patent Classification (IPC) or to both National Classification and IPC Int.Cl.5                      A 61 K 37/14                      A 61 K 45/06		
<b>II. FIELDS SEARCHED</b>		
Minimum Documentation Searched <sup>7</sup>		
Classification System	Classification Symbols	
Int.Cl.5	A 61 K	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched <sup>8</sup>		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT<sup>9</sup></b>		
Category *	Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>
X	Proceedings of the American Association for Cancer Research, vol. 32, March 1991, B.A. TEICHER et al.: "Combination treatment with a purified hemaglobin preparation and antitumor alkylating agents (AA) in the F5a1C fibrosarcoma", page 387, abstract no. 2302, see abstract & 82 Ann. Meeting, Houston, 15-13 May 1991 <div style="text-align: center; margin-top: 10px;">           ---                      -/-         </div>	1-9
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>* Special categories of cited documents: <sup>10</sup></p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"A" document member of the same patent family</p> </div> </div>		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
21-09-1992	29. 10. 92	
International Searching Authority	Signature of Authorized Officer	
EUROPEAN PATENT OFFICE	Mme Dagmar FRANK	

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
P,X	<p>Biomaterials, Artificial Cells, and Immobilization Biotechnology, vol. 19, no. 2, 1991, B.A. TEICHER et al.: "Effect of a bovine hemoglobin preparation (PBHS) on the response of two murine solid tumors to radiation therapy and chemotherapeutic alkylating agents", page 491, see abstract &amp; VIII World Congress of the International Society for Artificial Organs and the IV International Symposium on Blood Substitutes, Montreal, Quebec, 19-23 August 1991</p> <p>---</p>	1-9
P,X	<p>J. Cancer Res. Clin. Oncol., vol. 118, no. 2, February 1992, Springer-Verlag, B.A. TEICHER et al.: "Effect of a bovine hemoglobin preparation on the response of the F5aIIC fibrosarcoma to chemotherapeutic alkylating agents", pages 123-128, see the whole article</p> <p>---</p>	1-9
Y	<p>Int. J. Radiat. Oncol. Biol. Phys., vol. 19, suppl. 1, 1990, B.A. TEICHER et al.: "Effect of oxygen level on the enhancement of tumor response to radiation by perfluorochemical emulsions (PFCEs) or hemoglobin", page 137, abstract no. 27, see abstract &amp; 32 Annual ASTRO Meeting, Miami Beach, 15-19 October 1990</p> <p>---</p>	1-9
Y	<p>STN International, File CA, Chemical Abstracts, vol. 101, no. 23, (Columbus, Ohio, US), see abstract no. 204312s, &amp; JP,A,59130812 (GREEN CROSS CORP.) 27 July 1984, see abstract</p> <p>-----</p>	1-9